Cross-sectional and prospective impact of reallocating sedentary time to physical activity on children's body composition

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Running title: Reallocating sedentary time to activity

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What is already known about this subject

– The majority of children and adolescents are not sufficiently active according to public health recommendations.

– Isotemporal substitution analysis is an analytical approach used to understand the time substitution effects of replacing a fixed amount of time spent sedentary with physical activity on a specific outcome of interest.

What this study adds

– Isotemporal analysis suggests that substituting sedentary time with moderate and vigorous intensity physical activity, is associated with a favourable body composition over time in children.

– Physical activity of higher intensities appears more important in relation to improve body composition phenotypes in young people than activities of lighter intensity.

Abstract

Background: The amount of time children spend in sedentary behaviours may have adverse health effects. **Objective:** To examine the substitution effects of displacing a fixed duration of sedentary time with physical activity (PA) on children's body composition. **Methods:** We included 386 children (197 boys). Outcomes were BMI, waist circumference (WC), total body fat mass (TBFM) and trunk fat mass (TFM) assessed by dual-energy X-ray absorptiometry. Sedentary time and PA were measured with accelerometers. Data were analysed by isotemporal analyses estimating the effect of reallocating 15 and 30 min/day of sedentary time into light (LPA), and moderate-to-vigorous (MVPA) PA on body composition. **Results:** Reallocating 15 and 30 min/day of sedentary time into MVPA was negatively associated with body fatness in cross-sectional analyses. Prospectively, reallocating 30 minutes of sedentary time into 30 minutes of MVPA was negatively associated with WC (β=-1.11, p<0.05), TFM (β=-0.21, p<0.05), and TBFM (β=-0.48, p<0.05) at follow up (20 months). The magnitude of associations was half in magnitude and remained significant (p<0.05) when reallocating 15 minutes of sedentary time into MVPA. Reallocating sedentary time into LPA was not related (p>0.05) with body fatness outcomes. **Conclusions:** Substituting sedentary time with MVPA using isotemporal analysis is associated with positive effects on body composition..

Introduction

The majority of children and adolescents are not meeting the current public health recommendations for physical activity (PA) (1-3). Additionally, children and adolescents spend a considerable amount of time in sedentary behaviours (2,3). Although the health consequences of high amounts of time spent sedentary appear to be attenuated by time spent in moderate (MPA) and vigorous intensity activity (VPA) (4), others have suggested that time spent in sedentary behaviours may have adverse health implications (5).

In any given 24-hour period time is finite and increasing time spent sedentary displaces time spent in PA assuming sleep in constant. Isotemporal substitution analysis (6-8) is a fairly new analytical approach used to understand the effect of replacing an equal amount of time spent sedentary with PA on a selected outcome of interest [e.g., the effect of replacing 30 min/day of sedentary time with 30 min/day of light (LPA), MPA, VPA, and moderate-to-vigorous PA (MVPA) on trunk fat].

One previous study using the isotemporal substitution model in US youth observed that replacing 60 minutes of sedentary time with an equal amount of time spent in MVPA was associated with reductions in adiposity markers (6). However, due to the cross-sectional design it was not possible to determine the direction of associations between activity behaviours and adiposity. Thus, it is currently unclear whether substituting sedentary time with an equal amount of time spent in PA is prospectively associated with a more favourable body composition in young people. Therefore, the aim of this study was to examine the substitution effects of displacing a fixed duration of sedentary time with a fixed duration of LPA and MVPA on children's body composition.

Methods

Study design and population

Children were recruited from schools with fifth grade classes (6 schools, 1042 participants) from the Oeiras Municipality, in Lisbon Metropolitan area, Portugal. These schools participated in a school-based cluster randomized controlled trial (clinical trial registry: ISRCTN76013675) to evaluate the impact of an intervention in childhood obesity between 2010 and 2011, as described previously (9,10). For the present study a sub-sample including 386 children (197 boys, 189 girls) in which body composition was assessed by dual energy X-ray absorptiometry (DXA) at baseline and follow up after two school years, in combination with data on free living PA and sedentary time were included. The study protocol was approved by the Scientific Committee of the Faculty of Human Kinetics of University of Lisbon, the Portuguese Minister of Education, and Foundation of Science and Technology and all parents or legal guardians provided written informed consent.

Body composition measures

Height was measured barefoot and wearing minimal clothes to the nearest 0.5 cm, and body weight was measured to the nearest 0.1 kg on an electronic scale (model 770, Seca; Hamburg, Deutschland). Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters. Waist circumference (WC) was assessed with a flexibility measuring tape (Lufkin W606 PM, Apex Tool Group, Sparks, MD, USA) to the nearest 0.1 cm around the waist, at the smallest circumference between the iliac crest and the lower ribs. BMI and WC are reliable screening tools for identifying cardio-metabolic risk (11). DXA whole-body scan was performed to assess trunk fat mass (TFM) and total body fat mass (TBFM) (Hologic Explorer-W, fan-beam densitometer, software QDR for Windows version. 12.4, Hologic). TFM was used as an estimate of a central pattern of fat (visceral and subcutaneous), and TBFM was used as an estimate of total body fatness. The same technician positioned the participants, performed the scans and executed the analysis according to the operator’s manual using the standard analysis protocol. The scans were performed in the morning. Quality control using a spine phantom was conducted each morning prior to the assessments, and with a step phantom every week throughout the measurement period.

Physical activity and sedentary time

PA and sedentary time were measured with acceleromety (GT1M Actigraph, Actigraph Corporation, Pensacola, Florida, US). The monitor was attached tightly to the right hip using an elastic belt and children were instructed to wear the accelerometer during all waking hours except while bathing or other water-based activities. The length of the sampling interval was set at 15 seconds to allow a more refined estimate of PA intensity (12). Data were downloaded to a computer and an automated data reduction program (MAHUFFE) was used to analyse the data. Sequences of consecutive periods with >60 minutes of consecutive zero values were identified and defined as missing data. At least three days of recording (two weekdays and one weekend day) including a minimum of 600 minutes was required for inclusion in analysis. Activity counts were summed for each hour that the accelerometer was worn between 7:00 AM and 24:00 PM. Overall activity levels were expressed as total counts divided by measured time (counts/min). Time (min/day) spent in different sub-components of PA were calculated using the following intensity thresholds; <100 for sedentary time, 100 to 2019 for LPA, 2020 to 5998 for MPA, and ≥5999 for VPA (13,14).

Data analysis

Mean and standard deviation were calculated for baseline and follow up characteristics for the whole sample. Student's t-tests for paired samples was used to examine differences between baseline and follow up characteristics. Linear regression modelling employing an isotemporal substitution approach was used to quantify the cross-sectional and prospective associations of substituting a defined amount of sedentary time with LPA, and MVPA on body composition measures (BMI z score, WC, TFM, TBFM). Isotemporal substitution takes into account that time is finite during waking hours. For the present study all activity intensities were entered into the model at the same time. By holding total time constant and expressing the behaviours as a function of 30 and 15-minute time periods, the models estimated the effect of reallocating 30 and 15 min/day spent sedentary into an activity intensity (e.g. MVPA) on body composition (e.g. BMI z-scores, WC, TFM, TBFM). No significant interactions by sex were found. Therefore, all analyses were performed combining boys and girls and adjusted for age, sex, and accelerometer wear time (hrs/day). In prospective analysis, results were further adjusted for baseline body composition outcomes variables. Assumptions of linearity were verified and multicollinearity was checked using the variance inflation factor (VIF). VIF values were less than 5 in all analysis, indicating that multicollinearity was low. All statistical analyses were performed using IBM SPSS Statistics 22.0. The level of significance was set at 0.05.

Results

Children's characteristics at baseline and follow up are presented in table 1. Anthropometric and body composition variables all increased significantly between baseline and follow up (t(386)=-27.698, p<0.001), WC (t(386)=-11.396, p<0.001), TFM (t(386)=-8.225, p<0.001) and TBFT (t(386)=-10.659, p<0.001). A significant decrease in BMI z-score (t(386)=2.015, p=0.045), LPA (t(386)=4.548, p<0.001), and MVPA (t(386)=1.987, p=0.048) were observed. Sedentary time increased by 18 minutes per day (p=0.061).

***** Table 1 *****

Table 2 displays the results of the 30 minutes isotemporal substitution models for the cross-sectional and prospective analysis. In cross-sectional analysis, reallocating 30 minutes of sedentary time per day into 30 minutes of MVPA was negatively associated with BMI z-score (β=-0.21, 95% CI: -0.39 to -0.03, p<0.05), TFM (β=-0.81, 95% CI: -12.60 to -0.36, p<0.001), and TBFM (β=-1.62, 95% CI: -2.52 to -0.69, p<0.01). In prospective analyses, reallocating 30 minutes per day of sedentary time into 30 minutes of MPA or MVPA was negatively associated with WC (β=-1.11, 95% CI: -2.16 to -0.06, p<0.05), TFM (β=-0.21, 95% CI: -0.39 to -0.01, p<0.05), and TBFM (β=-0.48, 95% CI: -0.87 to -0.06, p<0.05) in follow up.

***** Table 2 *****

Table 3 presents the results of the substitution estimating the effect of reallocating 15 minutes per day of sedentary time into LPA and MVPA on body composition, for cross-sectional and prospective analysis. As expected, the magnitude of associations were half for 15 minutes substitution compared to the 30 minutes substitution. MVPA were negatively related with BMI z-score (β=-0.11, 95% CI: -0.20 to -0.01, p<0.05), TFM (β=-0.41, 95% CI: -6.30 to -0.18, p<0.001), and TBFM (β=-0.81, 95% CI: -1.26 to -0.35, p<0.01) in cross-sectional analysis. Prospectively, reallocating 15 minutes per day of sedentary time into MVPA was negatively associated with WC (β=-0.56, 95% CI: -1.08 to -0.03, p<0.05), TFM (β=-0.11, 95% CI: -0.20 to -0.00, p<0.05), and TBFM (β=-0.24, 95% CI: -0.44 to -0.03, p<0.05).

***** Table 3 *****

In both cross-sectional and prospective analysis reallocating 30 or 15 minutes of sedentary time into LPA were not associated with any body composition phenotypes.

Discussion

To our knowledge, this is the first study that used isotemporal substitution methods to examine the prospective associations of displacing a fixed duration of sedentary time with a fixed duration of different intensities of physical activity on children's body composition. Our results suggested that reallocating 30 or 15 minutes of sedentary time into 30 or 15 minutes of MVPA was associated with lower WC, TFM and TBFM. Prospectively, reallocating 30 minutes per day of sedentary time into MVPA was associated with a 1.11 cm reducing of WC, and 0.21 kg reducing of TFM and 0.48 kg reducing of TBFM. In contrast, reallocating sedentary time into LPA did not affect body composition phenotypes.

Our results are in agreement with previous cross-sectional observations in children (6), and adults with type 2 diabetes (15). Therefore, efforts aimed at replacing time spent in sedentary behaviours with MVPA appears effective in relation to young people's body composition. Since screen-based activities are the primary source of children's leisure time sedentary behaviours (16), one possible strategy could be reducing the amount of time children spend on computer, talking on mobile phones, or playing videogames. Reducing sedentary time in combination with promotion of organized sports suitable for all youth may have favourable implications, because organized sports appears to contribute to increased MVPA and the proportion of youth meeting PA recommendations (17). Another potential strategy to accomplish this is to integrate high-intensity activity bouts during children's school recess (18), or encourage physical education teachers to increase PA intensities in their classes. The last suggestion appears feasible, because it seems possible to increase MVPA in physical education classes without compromising students' intrinsic motivation, perceived competence or planned lesson objectives (19).

The present results add to some previous prospective studies suggesting a negative association between MVPA and adiposity indexes in youth (9,20, 21). Importantly, it appears the magnitude of association between physical activity and adiposity is greater with higher intensity (9, 21). However, some longitudinal studies have also suggested that sedentary time is related to weigh gain (22) and gain in BMI (23), and higher amounts of screen time may increases the risk of obesity (24). Taken together, this suggest that reducing sedentary time by reallocating the same amount of time into MVPA may positively influence on childhood adiposity. However, reallocating 30 minutes per day of sedentary time into MVPA may not be feasible for most children. It is therefore encouraging to note that a more realistic target; i.e. substituting 15 minutes of sedentary time by 15 minutes of MVPA also produced favourable, prospective reductions in WC, TFM and TBFM.

The results from these analyses are important for public health. Despite some reports indicate a levelling off in the prevalence of overweight and obesity in young people (26, 27) others suggest a steady increase (28). Therefore, replacing part of the awake time spent in sedentary behaviours by the same amount of time in MVPA may have favourable effects on incident obesity in youth.

Strengths of this study include the use of a fairly novel analytical method to examine the theoretical effects of displacing a fixed duration of sedentary time with a fixed duration of different PA intensities on children’s body composition. Furthermore, this study include a relatively large sample of children in which objective methods was used to assess PA, sedentary time, and adiposity indexes (BMI, WC, TFM, TBFM), thereby reducing measurement errors and recall bias associated with self-reported measures. Baseline and follow-up data were collected by the same trained staff, which likely reduced the possibility of random measurements error. Exposure and outcome variables were analysed in their continuous form, decreasing the likelihood of the loss of statistical power that normally occurs when categorical variables are used.

Despite these strengths, this study is not without limitations. First, the time interval between measurements was relatively short, equivalent to two school years. Future studies with longer duration of follow-up throughout adolescence are warranted, due to the marked decline in MVPA and increase in time spent sedentary by increasing age (3). Further, we cannot rule out our results are explained by residual confounding due to unmeasured or poorly measured confounders (e.g. socioeconomic status, birth weight and early life growth and genotype). Finally, our study is limited by lack of data on dietary intake, which may affect the observed associations.

In summary, isotemporal analysis suggests that replacing sedentary time with an equal amount of time in MVPA is associated with a favourable body composition in children. These results were consistent in cross-sectional and prospective analyses and highlights the importance of promoting PA of higher intensities such as organized sports, which may be important to reduce the prevalence of overweight and obesity and improve body composition phenotypes in young people. Prospective studies with longer duration of follow up are required to determine whether the effects last into older ages. Furthermore, it may also be important to determine whether the frequency breaks in sedentary time and thus a subsequent increased in LPA are associated with favourable effects on adiposity markers.

Conflicts of interest statement

None to declare

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Conception and design: LBS and AM; data acquisition: LBS and CM; data analysis and interpretation: AM, LBS and UE; drafting the manuscript: AM, LBS; critical revision for intellectual content: UE; statistical expertise: AM; administrative, technical or material support: CM; study supervision: LBS.

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Table 1. Characteristics, body composition and physical activity characteristics of the participants.

	Total (n=386)			Boys (n=197)			Girls (n=189)		
	Baseline (M±SD)	Follow up (M±SD)	*p*	Baseline (M±SD)	Follow up (M±SD)	*p*	Baseline (M±SD)	Follow up (M±SD)	*p*
Age (years)	9.94±0.58	11.55±0.69	<0.001	9.97±0.57	11.56±0.61	<0.001	9.90±0.63	11.54±0.76	<0.001
Weight (kg)	38.78±8.65	46.52±10.68	<0.001	37.81±8.63	45.35±11.86	<0.001	39.71±8.59	47.58±9.41	<0.001
Height (m)	1.43±0.07	1.52±0.09	<0.001	1.42±0.07	1.51±0.09	<0.001	1.43±0.07	1.53±0.08	<0.001
BMI	18.89±3.35	20.02±3.89	<0.001	18.65±3.50	19.57±4.00	<0.001	19.12±3.19	20.42±3.75	<0.001
BMI z-score	-0.02±0.96	-0.01±1.04	0.045	-0.05±1.02	-0.08±1.06	0.002	0.01±0.90	0.05±1.02	0.950
Waist circumference (cm)	69.89±9.03	73.91±9.14	<0.001	69.27±9.39	73.86±9.89	<0.001	70.45±8.68	73.96±8.44	<0.001
Trunk fat mass (kg)[1]	4.16±2.59	4.65±2.74	<0.001	3.67±2.59	4.01±2.70	<0.001	4.63±2.50	5.26±2.65	<0.001
Total body fat mass (kg)[1]	11.13±5.42	12.44±5.86	<0.001	10.10±5.56	11.09±5.88	<0.001	12.12±5.11	13.74±5.55	<0.001
Sedentary time (min/day)	522.23±63.64	540.14±72.88	0.061	518.2+-7±59.19	541.06±80.12	0.215	525.35±67.05	539.40±66.74	0.164
LPA (min/day)	238.94±38.97	226.63±42.71	<0.001	235.94±38.57	232.94±45.81	0.499	241.51±39.26	221.52±39.45	<0.001
MVPA (min/day)	59.35±22.26	54.72±23.85	0.048	65.91±24.54	62.25±22.83	0.861	53.74±18.42	48.63±22.98	0.008

M, mean; SD, standard deviation; BMI, body mass index; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity

[1] Measured by dual energy X-ray absorptiometry (DXA).

Differences between baseline and follow up were tested by Paired Student's t-test.

Table 2. Cross-sectional and prospective association of substituting 30 min of sedentary time for different physical activity intensity levels with body composition.

Replace 30 minutes of sedentary time with 30 minutes of:	Body mass index z-score β (95% CI)	Waist circumference (cm) β (95% CI)	Trunk fat mass (kg) β (95% CI)	Total body fat mass (kg) β (95% CI)
Cross-sectional analysis				
Light PA	0.03 (-0.09, 0.12)	0.21 (-0.81, 1.23)	-0.09 (-0.36, 0.15)	-0.27 (-0.78, 0.27)
MVPA	-0.21 (-0.39, -0.03)*	-1.32 (-3.06, 0.42)	-0.81 (-12.60, -0.36)***	-1.62 (-2.52, -0.69)**
Prospective analyses				
Light PA	0.03 (-0.06, 0.09)	-0.21 (-0.87, 0.45)	0.03 (-0.09, 0.15)	0.09 (-0.15, 0.33)
MVPA	-0.06 (-0.18, 0.06)	-1.11 (-2.16, -0.06)*	-0.21 (-0.39, 0.00)*	-0.48 (-0.87, -0.06)*

PA, physical activity; MVPA, moderate-to-vigorous physical activity; CI, confidence interval

In cross-sectional analysis results were adjusted for age, sex, and accelerometer wear time (hrs/day). In prospective analysis results were further adjusted for baseline body composition outcomes variables.

*$p<0.05$, **$p<0.01$, ***$p<0.001$

Table 3. Cross-sectional and prospective association of substituting 15 minutes of sedentary time for different physical activity intensity levels with body composition.

	Body mass index (kg/m^2)	Waist circumference (cm)	Trunk fat mass (kg)	Total body fat mass (kg)
Replace 15 minutes of sedentary time with 15 minutes of:	z-score β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Cross-sectional analysis				
Light PA	0.02 (-0.05, 0.06)	0.11 (-0.41, 0.62)	-0.05 (-0.18, 0.08)	-0.14 (-0.39, 0.14)
MVPA	-0.11 (-0.20, -0.02)*	-0.66 (-1.53, 0.21)	-0.41 (-6.30, -0.18)***	-0.81 (-1.26, -0.35)**
Prospective analyses				
Light PA	0.02 (-0.03, 0.05)	-0.11 (-0.44, 0.23)	0.02 (-0.05, 0.08)	0.05 (-0.08, 0.17)
MVPA	-0.03 (-0.09, 0.03)	-0.56 (-1.08, -0.03)*	-0.11 (-0.20, 0.00)*	-0.24 (-0.44, -0.03)*

PA, physical activity; MVPA, moderate-to-vigorous physical activity; CI, confidence interval

In cross-sectional analysis results were adjusted for age, sex, and accelerometer wear time (hrs/day). In prospective analysis results were further adjusted for baseline body composition outcomes variables.

*p<0.05, **p<0.01, ***p<0.001